Numerical Studies of Rough Surface Scattering Models

Shira Lynn Broschat
School of Electrical Engineering and Computer Science
Washington State University
P.O. Box 642752
Pullman, WA 99164-2752
phone: (509) 335-5693 fax: (509) 335-3818 email: shira@eecs.wsu.edu

Award Number: N000140410201
http://www.eecs.wsu.edu/~shira/

LONG-TERM GOALS

To develop a practical set of rough surface scattering strength equations for use in real-world Navy applications.

OBJECTIVES

To examine and develop theoretical surface scattering models that accurately predict bistatic acoustic wave scattering at the air-sea interface and at the ocean-bottom interface in shallow water at very low grazing angles.

APPROACH

It is very difficult to accurately model scattering from rough surfaces at very low grazing angles. This is because scattering levels are very low and multiple scattering of both the incident and scattered fields cannot be ignored. Unfortunately, this multiple scattering usually corresponds to complex expressions for the bistatic scattering strength that are difficult to calculate.

A number of years ago A.G. Voronovich introduced the non-local small slope approximation and showed that it includes some multiple scattering [1]. Broschat and Thorsos derived cross section equations for this model and obtained numerical results for the scattering strength that were accurate close to grazing angles [2]. However, the scattering strength equations were computationally complex (requiring quintuple integration of highly-oscillatory, infinite integrals for just the 1-D surface problem) and impractical. In the ensuing years since these results were shown, the PI has worked to develop a model for scattering at very low grazing angles that is practical. The model has been termed the SSA+ ("small slope approximation plus") because its first term is identical to the expression for the lowest-order small slope approximation cross section, while its second term contains multiple scattering that improves the results for the SSA at very low grazing angles. For the 1-D surface problem, the SSA+ requires double integration at very low grazing angles and single integration away from low grazing angles.

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WORK COMPLETED

The PI and her graduate student have completed the following work for scattering at very low grazing angles:

- Derivation of the scattering cross section for 1-D, pressure-release surfaces.
- Development of proper limits of integration for the SSA+.
- Numerical implementation of the scattering cross section for 1-D, pressure-release surfaces for three different spectra.
- Development of an iterative method to obtain Monte Carlo integral equation results for surfaces up to 3250 wavelengths in length.
- Benchmarking of the SSA+ results for scattering at very low grazing angles in both the forward and backward directions using Monte Carlo implementations of the integral equation technique, KA, SSA, and SSA+ for 1-D, pressure-release surfaces.
- Derivation and numerical implementation of the scattering cross section for 1-D, fluid-fluid interfaces.
- Derivation and numerical implementation of the scattering cross section for 2-D, pressure-release surfaces.
- Derivation and numerical implementation of the scattering cross section for 2-D, fluid-fluid interfaces

RESULTS

A paper has been submitted describing the SSA+ work for the Dirichlet problem. In this paper we derived the bistatic scattering cross section equation for the SSA+ from the non-local small slope approximation (NLSSA). Three approximations were used which reduced the NLSSA cross section to the sum of the lowest-order SSA cross section and a correction term that includes some multiple scattering. Numerical results for the SSA+ cross section were presented for scattering at very low grazing angles ($\leq 5°$) for an angle of incidence of 80°. For the single-scale Gaussian roughness spectrum, results were limited to the forward direction, but for the multiscale Pierson-Moskowitz and modified power law spectra, results were given for scattering in both the forward and backward directions. Results for the PM spectrum are shown in Figures 1 and 2.

Criteria were presented for what constitutes a practical scattering cross section, and the SSA+ met all three criteria for forward scattering up to an angle of scatter of 89.8° for all the cases considered. In the back direction, the SSA+ results were more modest, meeting the criteria for angles of scatter up to $-89.8°$ but not for all cases studied.

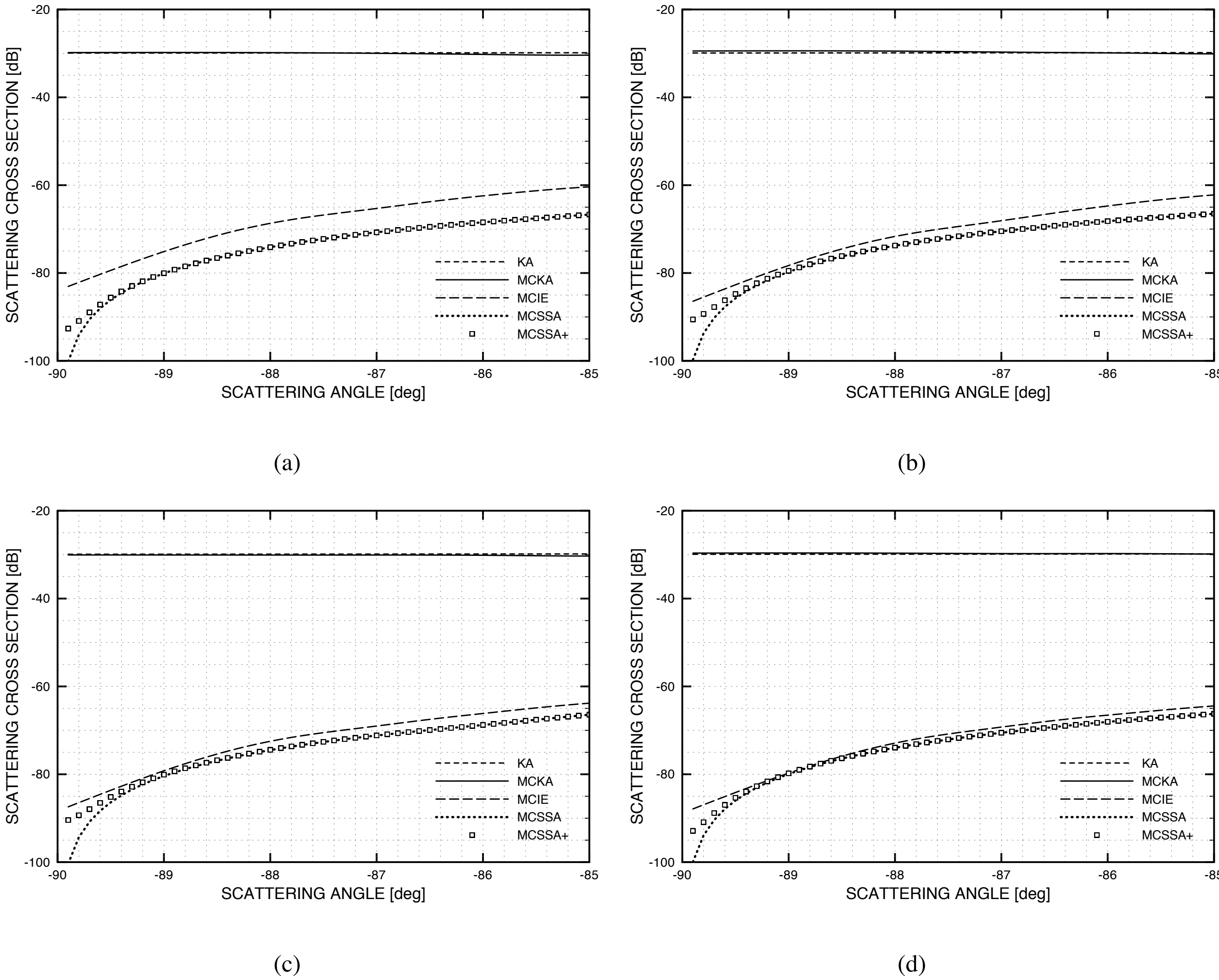

Figure 1: Pierson-Moskowitz roughness spectrum results for low backscatter for an angle of incidence of $\theta_i = 80^\circ$ for the Kirchhoff approximation (KA) and Monte Carlo Kirchhoff approximation (MCKA), integral equation (MCIE), small slope approximation (MCSSA), and SSA+ (MCSSA+). (a) The wind speed $\boldsymbol{u}$ = 5 m/s, and the incident wavelength is 23 cm. (b) The wind speed $\boldsymbol{u}$ = 5 m/s, and the incident wavelength is 50 cm. (c) The wind speed $\boldsymbol{u}$ = 5 m/s, and the incident wavelength is 80 cm. (d) The wind speed $\boldsymbol{u}$ = 10 m/s, and the incident wavelength is 3.75 m.

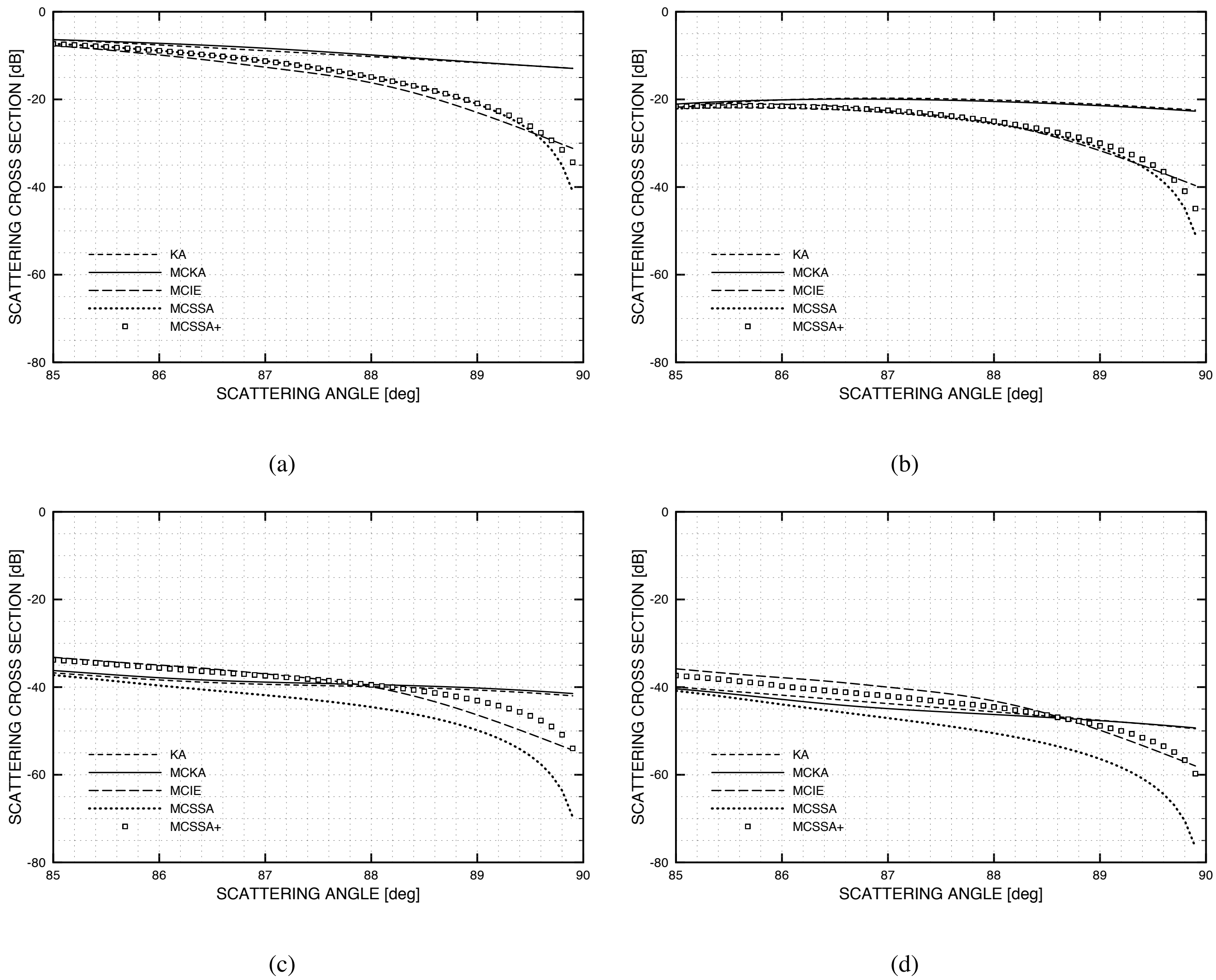

Figure 2: Pierson-Moskowitz roughness spectrum results for low forward scatter for an angle of incidence of $\theta_i = 80°$ for the Kirchhoff approximation (KA) and Monte Carlo Kirchhoff approximation (MCKA), integral equation (MCIE), small slope approximation (MCSSA), and SSA+ (MCSSA+). (a) The wind speed $\boldsymbol{u}$ = 5 m/s, and the incident wavelength is 23 cm. (b) The wind speed $\boldsymbol{u}$ = 5 m/s, and the incident wavelength is 50 cm. (c) The wind speed $\boldsymbol{u}$ = 5 m/s, and the incident wavelength is 80 cm. (d) The wind speed $\boldsymbol{u}$ = 10 m/s, and the incident wavelength is 3.75 m.

IMPACT/APPLICATIONS

The development of approximate models that accurately predict wave scattering from rough surfaces is important in a number of Navy applications. For example, rough surface scattering models are needed in the simulations used by torpedo guidance and control personnel to test torpedoes. Another application for which rough surface scattering is critical is the detection of underwater mines, especially those buried in soft sediments. Other applications include ship wake detection, communications, and anti-submarine warfare. Of particular importance is that the models be as simple as possible while retaining the physical information necessary for the application.

Much of the knowledge we have gained has been disseminated via publications and conference presentations. A search of Google Scholar online shows that previous ONR-sponsored work on rough surface scattering has been cited 334 times, and it is believed that the SSA+ has the potential to be of practical use to the Navy.

RELATED PROJECTS

This work is related to research in shallow water acoustics, high-frequency acoustics, and long-range propagation. The SSA+ is of particular interest when forward scatter is important since it includes nonlocal interactions. In addition, the PI is collaborating with John Schneider to develop a finite-difference time-domain method for obtaining Monte Carlo integral equation results, which allows use of an infinite plane wave incident on a finite-length surface. For a given-length surface the method will provide much better angular resolution than that obtainable using an incident tapered plane wave.

REFERENCES

1. Voronovich, A.G., “Non-local small-slope approximation for wave scattering from rough surfaces,” *Waves in Random Media*, vol. 6, pp. 151-167, 1996.

2. Broschat, S.L., and E.I. Thorsos, “A preliminary numerical study of the non-local small slope approximation,” *J. Acoust. Soc. Am.*, vol. 100, p. 2702, 1996.

PUBLICATIONS

S.L. Broschat and Y. Wang, “A practical cross section for scattering from rough surfaces at very low grazing angles in both the forward and backward directions,” submitted to *Waves in Random and Complex Media*,” Aug. 2008.